METHOD OF FABRICATING A SEMICONDUCTOR DEVICE

TECHNICAL FIELD

The present invention relates generally to the manufacture of semiconductor devices, and more particularly to manufacture of contacts and/or vias that include conductive plugs.

BACKGROUND OF THE INVENTION

Continuing advances in semiconductor manufacturing processes have resulted in semiconductor devices with finer features and/or higher degrees of integration. Among the various features that may be included within a semiconductor device are contact structures (including "vias") that typically provide an electrical connection between circuit devices and/or layers. The above-mentioned advances have led to contact structures with smaller sizes and/or higher aspect ratios. A contact aspect ratio may be the ratio between a contact depth and width.

A typical contact structure may include forming a contact hole in an insulating layer and then filling such a contact hole. Contact structures with smaller contact sizes and/or higher aspect ratios can be more difficult to fill than larger contacts and/or contacts with lower aspect ratios. Consequently, a contact filling material is often selected for its ability to adequately fill a contact hole.

Two common conductive materials that may be included in a semiconductor manufacturing process are aluminum and copper. Such materials have been included in interconnect patterns and the like. However, it has been difficult to form small and/or high aspect ratio contacts with aluminum. Similarly, while can copper provides advantageously low resistance, it is believed that many technical problems may have to be overcome before

copper contact structures may be practically implemented. In view of the above drawbacks to materials such as aluminum and copper, many conventional contact forming methods include tungsten as a contact filling material.

One method of forming contact structures with tungsten includes a selective tungsten chemical vapor deposition (W-CVD) method. In a selective W-CVD method, tungsten may be deposited essentially only on silicon exposed at the bottom of a contact hole. It is believed that current conventional selective W-CVD methods are not sufficiently reproducible to provide satisfactory results in a manufacturing process. Further, adverse results may result when selective W-CVD methods are used to fill contacts having depths that vary. More particularly, a contact hole that is shallow with respect to the other contact holes may suffer from excessive growth (overgrowth) of tungsten in the contact hole. Overgrowth of tungsten may then be corrected with an etch back step that removes only overgrown portions. However, such an etch back step can add to the complexity and/or cost of a manufacturing process.

In light of the drawbacks present in selective W-CVD approaches, conventional "blanket" W-CVD methods are widely used for filling contact holes. In a blanket W-CVD method, contact holes may be formed in an insulating layer. Tungsten may then be deposited over the surface of the insulating layer, filling the contact holes. Deposited tungsten may then be etched back to remove tungsten from the top surface of the insulating layer while tungsten within the contact holes remains. Tungsten remaining within a contact hole is often referred to as a tungsten "plug."

A conventional method for forming a tungsten plug in a contact with a blanket W-CVD method will now be described with reference to FIGS. 3A-3D and 4A-4B.

In a conventional contact formation process, an interlayer insulating film **002** may be formed on a silicon substrate **001** that includes an impurity diffusion region **011**. An interlayer insulating film **002** may include silicon dioxide (SiO_2), for example. A contact hole **020** may then be formed through the interlayer insulating film **002** to the impurity diffusion region **011**. A structure following the formation of such a contact hole **020** is shown in FIG. 3A.

Referring now to FIG. 3B, a titanium film **003** may be deposited on the surface of the interlayer insulating film **002**, including within the contact hole **020**. A titanium film **003** may be deposited with a conventional sputtering method, and to a thickness in the range of about 20 nm to 50 nm. A conventional sputtering method may be isotropic. A titanium film **003** may serve as a barrier layer for subsequent contact materials, preventing such materials from diffusing into a semiconductor substrate **001**.

Referring now to FIG. 3C, following the deposition of a titanium film **003**, a titanium nitride film **004** may be deposited on the exposed surface, including within the contact hole **020**. A titanium nitride film **004** may be deposited with a reactive sputtering method, and to a thickness in the range of about 20 nm to 50 nm. In such a reactive sputtering method, a titanium target may be a source of titanium. Titanium particles from a target may react with nitrogen before reaching a device surface thereby providing titanium nitride as a sputtered material.

A layered film of titanium/titanium nitride **(003/004)** may serve as an adhesion layer for a subsequently deposited material, such as tungsten. Following the deposition of a layered titanium/titanium nitride film **(003/004)**, a temperature cycling step may be used to further improve the adhering characteristics of such a layered film. As but one example, a

ramp anneal may be performed at 650° C for 30 seconds. Such a ramp anneal may result in a reaction between the film materials, as well as a reaction between a titanium film **003** and an interlayer insulating film **002** that furthers the adhering characteristics of the layered film.

Referring now to FIG. 3D, a layer of tungsten **005** may then be deposited over a layered of film of titanium/titanium nitride (**003/004**). A tungsten deposition step may include a source gas that includes tungsten, such as tungsten hexafluoride (WF_6), as but one example. Such a deposition step may form a layer of tungsten **005** over a layered of film of titanium/titanium nitride (**003/004**), thereby filling a contact hole **020**.

An etch back step may then be performed that removes portions of tungsten on the interlayer insulating film **002** while leaving tungsten within a contact hole **020**, thereby forming a tungsten plug. Such a tungsten etch back step may include a fluorine containing gas. For example, tungsten may be plasma etched with sulfur hexafluoride (SF_6) as a source gas.

Following the etch back of tungsten, exposed portions of the layered titanium/titanium nitride (**003/004**) film may be removed with a chlorine containing gas. A contact structure following such a step is shown in FIG. 4A. The result may be a contact structure with a tungsten plug.

Following the formation of a tungsten plug, an interconnect film may be formed over a semiconductor substrate **001**, including over a tungsten plug. An interconnect film may include aluminum, as but one example. Such an interconnect film may then be patterned to form an interconnect structure **006**. A semiconductor device following the formation of an interconnect structure **006** is shown in FIG. 4B.

In this way, a conventional W-CVD process may be used to form a tungsten plug that

connects and interconnect structure **006** to a semiconductor substrate **001**.

A drawback to a conventional approach, such as that shown in FIGS. 3A-3D and 4A-4B, can be a resulting shape of a tungsten plug. More particularly, as shown in FIG. 4A, an upper portion tungsten **005** formed within a contact hole **020** may have a recess. Such a recess may be formed when a tungsten film **005** and/or layered titanium/titanium nitride film (**003**/**004**) is etched back. More particularly, such layers may essentially be overetched to help ensure that residual tungsten, titanium and/or titanium nitride is not left on a surface of interlayer insulating film **002**. Such an overetching can remove an upper portion of tungsten **005** that is within a contact hole **020**.

A recess in an upper portion of a tungsten plug (i.e., increased "plug loss"), can result in worse step coverage for an overlying interconnect structure **006**. FIG. 4B shows such an arrangement. An interconnect structure **006** must extend into a portion of a contact hole **020**, over a step formed when a tungsten **005** top surface is lower than an interlayer insulating film **002** top surface. Such a structure may lead to undesirably increased resistance in an interconnect structure **006**. Further, in such a structure, material in an interconnect layer **006** may be more susceptible to electromigration.

Plug loss may also present difficulties for subsequent structures. For example, an interconnect structure **006** formed over a tungsten plug having a recess may have an uneven surface. A second interlayer insulating film may be formed over an interconnect structure **006**. A via hole may then be etched through the second insulating film to the interconnect structure **006**. The uneven surface of an interconnect structure **006** may make it difficult to remove all of a second insulating film. If all of the second insulating film is not removed, a via may have higher contact resistance.

FIG. 10 shows a conventional sputtering apparatus. Such an apparatus may be used to deposit a film of titanium as shown in FIG. 3B. A conventional sputtering apparatus may include a substrate holder **031**. A substrate holder **031** can hold a semiconductor substrate **032**, that is to be processed, in an essentially parallel orientation to a target **035**. A target **035** may be formed from a material that is to be deposited (e.g., titanium).

A magnet **033** may be disposed on one surface of the target **035**, while an opposite surface can face a semiconductor substrate **032**. A target **035** may also be connected to a DC power source **034**.

The application of a voltage to a target **035** can result in sputtering particles **037** being released from the target **035**. In the conventional approach illustrated, sputtering particles **037** can be incident on a semiconductor substrate **032** from various directions due to scattering. Consequently, a sputtering apparatus shown in FIG. 10 can provide isotropic sputtering particles.

One approach to addressing plug loss is disclosed in Japanese Laid-Open Patent Publication No. 9-321141. In particular, the publication shows a technique in which the thickness of a titanium nitride layer is thicker than the previously described approach. A titanium nitride layer may have a thickness in the range of 100-200 nm, instead of 20-50 nm. This technique will be explained with reference to FIGS. 5A-5D and 6A-6D.

In the technique of FIGS. 5A-5D and 6A-6D, an interlayer insulating film **002** may be formed on a silicon substrate **001** that includes an impurity diffusion region **011**. An interlayer insulating film **002** may include silicon dioxide (SiO_2), for example. A contact hole **020** may then be formed through the interlayer insulating film **002** to the impurity diffusion region **011**. A structure following the formation of such a contact hole **020** is

shown in FIG. 5A.

Referring now to FIG. 5B, a titanium film **003** may be deposited on the surface of the internal insulating film **002**, including within the contact hole **020**. A titanium film **003** may be deposited with a conventional sputtering method, and to a thickness of about 30 nm. A conventional sputtering method may be isotropic.

Referring now to FIG. 5C, following the deposition of a titanium film **003**, a titanium nitride film **004** may be deposited on the exposed surface, including within the contact hole **020**. A titanium nitride film **004** may be deposited with a reactive sputtering method, and to a thickness in the range of about 150 nm to 200 nm. A conventional reactive sputtering method may also be isotropic.

Referring now to FIG. 5D, a layer of tungsten **005** may then be deposited over a layered film of titanium/titanium nitride (**003/004**), thereby filling a contact hole **020**.

Referring now to FIG. 6A, an etch back step may then be performed that removes portions of tungsten on the interlayer insulating film **002** until a titanium nitride layer **004** is exposed. Such a tungsten etch back step may include a reactive plasma etch with sulfur hexafluoride (SF_6) and argon (Ar) as source gases.

Following the etch back of tungsten, exposed portions of the layered titanium/titanium nitride film (**003/004**) may be etched. Such an etching may be a two-stage process. In a first step, the layered titanium/titanium nitride film (**003/004**) may be etched with a reactive ion etch (RIE) having a high selectivity with respect to titanium nitride. Such a RIE step may remove titanium nitride **004** and can expose a titanium layer **003**. A structure following such a first step is shown in FIG. 6B.

In a second step, the layered titanium/titanium nitride film (**003/004**) may be etched

with a reactive ion etch (RIE) having a lower reactivity than that of the first step, described above. As but one example, such a second etching step may include a source gas flow rate ratio between chlorine gas (Cl_2) and argon gas (Ar) of about 1:30 and a high frequency power of about 450 W. Such a second step may remove portions of the layered titanium/titanium nitride film (**003/004**) on the surface of a interlayer insulating film **002**, thereby forming a tungsten plug, as shown in FIG. 6C.

As in the previously described conventional example, following the formation of a tungsten plug, an interconnect film may be formed over a semiconductor substrate **001**, including over a tungsten plug. An interconnect film may include aluminum, as but one example. Such an interconnect film may then be patterned to form an interconnect structure **006**. A semiconductor device following the formation of an interconnect structure **006** is shown in FIG. 6D.

In this way, a tungsten plug may be formed that has an upwardly projecting top portion, and not a recess, as is the case of methods that suffer from plug loss.

While the technique of FIGS. 5A-5D and 6A-6D can provide an approach for addressing plug loss, such an approach is not without disadvantages. Such disadvantages will now be described with reference to FIGS. 9A and 9B.

A first disadvantage can be insufficient filling of a contact hole. When a titanium nitride film **004** thickness is increased, the remaining space in a contact hole **020** that is to be filled with tungsten **005** can be significantly reduced. As noted above, a titanium nitride deposition method may be essentially isotropic. Consequently, the thicker titanium nitride film **005** can be formed on the side walls of a contact hole **020**. A resulting reduced contact space is shown in FIG. 9A. Such a reduced contact space can be harder to fill by

conventional tungsten deposition processes.

Further, an isotropic deposition of titanium nitride can result in an overhanging shape at the upper portion of a contact hole. One example of such an overhanging shape is shown in FIG. 9B. An overhanging shape can reduce the size of the top of a contact hole opening, making it more difficult to subsequently fill the contact hole.

As manufacturing technology continues to advance, contact holes (including via holes) continue to decrease in size. As but one example, contact holes of 0.3 μm or less may be formed. Thus, filling such smaller contact holes in light of the above disadvantage can become an increasingly more difficult task.

A second disadvantage can be an increase in plug resistance. In a technique such as that shown in FIGS. 5A-5D and 6A-6D, a thicker titanium nitride film can be formed on the inner walls of a contact hole. Thus, a contact may include more titanium nitride in cross section than is the case of other conventional methods. Because titanium nitride can have a higher resistance than tungsten, a contact structure according to FIGS. 5A-5D and 6A-6D can have a higher resistance than other conventional approaches.

A third disadvantage can be trenching (or "gouging") on a top portion of a contact structure. Such trenching may occur when titanium nitride is removed by etching. More particularly, when an adhering layer, such as titanium/titanium nitride (**003/004**) is etched, portions of the adhering layer at the top of a contact structure can be removed, leaving recesses. The formation of such recesses is often referred to as trenching. When adhering layers are relatively thin, such trenching can be relatively small. However, because such a layer is thicker in the method according to FIGS. 5A-5D and 6A-6D, trenching may be large with respect to other conventional approaches. If relatively large trenching occurs, contacts

with higher interconnect resistance and/or reduced electromigration resistance may result.

In the method according to FIGS. 5A-5D and 6A-6D, a two step etch method for removing an adhering film may reduce trenching in some cases. However, such a two step approach can add complexity to a manufacturing process. Further, while effective in some cases, such an approach may be less effective in other cases. In a particular, for contact holes having a diameter of 0.3 μm or less, effects of trenching are increased and may not be sufficiently addressed.

In light of the above discussion, it would be desirable to arrive at some way of forming contact structures that can prevent plug loss without incurring the drawbacks of insufficient contact hole filling, increased resistance, or trenching on the top of the contact structure.

SUMMARY OF THE INVENTION

According to the present invention, a semiconductor manufacturing process may include forming an insulating film on a semiconductor substrate. A contact hole may then be formed in the first insulating film. A titanium film may then be deposited over the first insulating film and in the contact hole. The titanium film may be deposited with an anisotropic sputtering method to a thickness outside the contact hole of 100 nm or more. A titanium nitride film may then be formed over the titanium film. A tungsten film can then be deposited over the titanium nitride film, including within the contact hole. A first etch step may then remove tungsten to expose the titanium nitride film outside the contact hole. One or more subsequent etch steps may then remove titanium and titanium nitride films outside the contact hole, thereby forming a tungsten plug. An interconnect conductive film may then

be formed over the tungsten plug.

According to one aspect of the present invention, by forming the titanium layer with an anisotropic sputtering method, the thickness of the titanium film outside a contact hole may be 100 nm or more, while the thickness of such a film within a contact hole may be substantially smaller. This can enable tungsten to be deposited in the contact hole with fewer defects. Further, when the titanium and titanium nitride films are removed, a tungsten plug may be formed with an upwardly projecting top portion.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A to 1D are side cross sectional views of a first embodiment.

FIGS. 2A to 2C are side cross sectional views of the first embodiment.

FIGS. 3A to 3D are side cross sectional views of a first conventional contact forming method.

FIGS. 4A and 4B are side cross sectional views of the first conventional contact forming method.

FIGS. 5A to 5D are side cross sectional views of a second conventional contact forming method.

FIGS. 6A to 6D are side cross sectional views of the second conventional contact forming method.

FIGS. 7A to 7D are side cross sectional views of a second embodiment.

FIGS. 8A to 8C are side cross sectional views of the second embodiment.

FIGS. 9A and 9B are side cross sectional views illustrating drawbacks to the second conventional contact forming method.

FIG. 10 is a diagram of a conventional sputtering apparatus.

FIG. 11 is a diagram of an ion metal plasma sputtering apparatus.

FIG. 12 is a diagram of a collimate sputtering apparatus.

FIG. 13 is a diagram of a long throw sputtering apparatus.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Various embodiments of the present invention will now be described to in detail with reference to a number of drawings.

A method for forming a contact structure according to a first embodiment will now be described in conjunction with a series of side cross sectional views shown in FIGS. 1A to 1D and 2A to 2C.

Referring now to FIG. 1A, a first embodiment may include forming an interlayer insulating film **002** over a substrate **001**. An interlayer insulating film **002** may comprise silicon dioxide (SiO_2), as but one example. A semiconductor substrate **001** may comprise silicon and include an impurity region **011** formed therein.

As shown in FIG. 1A, a contact hole **020** may be formed through an interlayer insulating film **002** to an impurity region **011** in a semiconductor substrate **001**. A contact hole **020** may have an aspect ratio greater than 5, more particularly about 6 or more. A contact hole **020** may also have an inner diameter less than 0.3 μm, more particularly about 0.2 μm, and a depth greater than 1.0 μm, more particularly about 1.2 μm.

As shown in FIG. 1B, a titanium film **003** may then be formed on the surface of the interlayer insulating film **002**, including within the contact hole **020**. A titanium film **003** may have a thickness outside a contact hole **020** of about 100 nm or more, preferably 150 nm

or more. A titanium film **003** thickness may be selected taking into account a contact hole diameter. For example, for the above titanium film **003** thickness, a contact hole may have a diameter of 300 nm or less, more preferably 250 nm or less.

A titanium film **003** thickness should preferably be large enough to prevent a recess in a subsequently formed plug, as will be discussed in more detail below. This can overcome the drawbacks of plug loss present in conventional approaches. If a titanium film **003** thickness outside a contact hole **020** is too thin, recesses may result, incurring the drawbacks discussed above.

It is also noted that a titanium film **003** should have a particular thickness within a contact hole **020**. If a titanium film **003** is too thin, it may not serve as an adequate barrier between a semiconductor substrate **001** and other contact materials. Further, if a titanium film **003** within a contact hole **020** is too thin, its adhering properties may be inadequate. On the other hand, if a titanium film **003** it too thick, a contact hole **020** opening may become so narrow, that subsequently filling the contact hole **020** may become problematic.

According to one embodiment, a titanium film **003** may be deposited with an anisotropic sputtering method. Such a method may generate sputtering particles that have a substantially vertical incidence with a semiconductor substrate. Thus, in an anisotropic sputtering method, sputtering particles have large vertical incidence components. In such an environment, the number of sputtering particles that adhere to vertical walls of a contact hole is reduced with respect to isotropic sputtering approaches. As a result, the thickness of a titanium film **003** outside a contact hole **020** may be substantially thicker than the titanium film **003** inside the contact hole **020**.

It will be recalled that previously described conventional approaches with isotropic

sputtering may form a titanium film having essentially the same thickness both inside and outside a contact hole. A thicker titanium film inside a contact hole may lead to increased contact resistance and/or difficulties in filling a contact hole. An anisotropic sputtering approach according to the present invention can overcome such drawbacks.

It will also be recalled that isotropic deposition of a contact material may form overhanging structures at the top of a contact hole. Overhanging structures can limit the size of a contact hole opening making it more difficult to fill the contact hole. An anisotropic sputtering approach according to the present invention can overcome this drawback as well.

While there may be various approaches to anisotropic sputtering according to the present invention, possible specific examples may include a collimate sputtering method, a "long throw" sputtering method, or an ion metal plasma method, to name but a few.

Of the various named methods, an ion metal plasma method may be preferable for contact and via holes having an aspect ratio greater than 5. An ion metal plasma method may form a film where the film thickness outside a contact hole is significantly greater than the film thickness on side walls inside the contact hole. Such differences in thickness can be particularly suitable for forming contact structures according to the present invention. In addition, an ion metal plasma method may provide better sputtering efficiency over other anisotropic sputtering methods.

An example of an ion metal plasma anisotropic sputtering method will now be described in more detail.

An ion metal plasma method can be a physical vapor deposition method that includes a coil that is driven with RF energy. Such a coil may be situated within a sputtering chamber and may ionize sputtering particles released from a target.

An ion metal plasma sputtering apparatus is shown in FIG. 11. An ion metal plasma sputtering apparatus may include a substrate holder **031**. A substrate holder **031** can hold a semiconductor substrate **032**, that is to be processed, in an essentially parallel orientation to a target **035**. A target **035** may be formed from a material that is to be deposited (e.g., titanium).

A target **035** may be connected to a DC power source **034** while a substrate holder **031** may be connected to ground. A magnet **033** may be disposed on one surface of the target **035**, while an opposite surface can face a semiconductor substrate **032**. The apparatus of FIG. 11 further includes a coil **036** disposed between the target **035** and the semiconductor substrate **032**. A coil **036** may be connected to a RF power source (not shown).

The application of a voltage to a target **035** can result in sputtering particles being generated. A coil **036** may generate a high-density inductively coupled RF plasma, which can ionize sputtering particles **039**. Such ionized sputtering particles **039** may then be influenced by the electrical field between the target **035** and the semiconductor substrate **032** to have a vertical incidence with a semiconductor substrate **032**. In this way, in an ion metal plasma method, sputtering particles **039** are ionized and then influenced by an electrical field to provide an essentially anisotropic sputtering of a material (e.g., titanium).

As but one specific example, an ion metal plasma method may have the following conditions. A sputtering chamber **030** pressure may be about 20 mTorr. A substrate temperature may be about 150 °C. A DC power may be about 2.3 kW. A RF power for a coil **036** may be about 2.8 kW.

Referring back to FIG. 1C, following the essentially anisotropic sputtering of titanium, a titanium nitride film **004** may be formed. A titanium nitride film **004**, like a

titanium film **003**, may serve as a barrier between the semiconductor substrate **001** and a subsequently formed plug material (e.g., tungsten). Further, a titanium nitride film **004** can improve the adherence of the subsequently formed plug material.

In one particular approach, a titanium nitride film **004** may be deposited with a reactive sputtering method. In such a reactive sputtering method, a titanium target may be a source of titanium, and titanium particles from a target may react with nitrogen before reaching a device surface.

In this way a layered film of titanium/titanium nitride **(003/004)** may be formed that serves as an adhesion layer and/or a barrier layer for a subsequently deposited material, such as tungsten.

Following the deposition of a layered titanium/titanium nitride film **(003/004)**, a temperature cycling step may be used to further improve the adhering characteristics of such a layered film. As but one example, a ramp anneal may be performed at 650° C for 30 seconds. Such a ramp anneal may result in a reaction between the film materials, as well as a reaction between a titanium film **003** and an interlayer insulating film **002** that furthers the adhering characteristics of the layered film.

Referring now to FIG. 1D, a tungsten film **005** may be deposited over a layered film of titanium/titanium nitride **(003/004)**. A tungsten deposition step may include a mixed gas that includes a tungsten source gas, such as tungsten hexafluoride (WF_6). In one particular arrangement, a tungsten film **005** may be deposited with chemical vapor deposition techniques at a temperature of about 400 °C and a pressure of about 6 Torr. Such a tungsten (W) chemical vapor deposition (CVD) step may form a layer of tungsten **005** over a layered of film of titanium/titanium nitride **(003/004)**, thereby filling a contact hole **020**.

Following the deposition of a tungsten film **005**, a tungsten film **005** can be etched back to form a plug. Preferably, a tungsten etch back step may have a degree of selectivity between tungsten and titanium nitride.

As but one specific example, a tungsten etch back step may be performed under the following conditions. Etch source gases may include sulfur hexafluoride (SF_6) flowing at about 110 standard cubic centimeters per minute (sccm) and argon (Ar) flowing at about 90 sccm. An etch chamber may be at a pressure of about 280 mTorr. Such an etch may be a reactive plasma etch with an RF power of about 600 W.

A tungsten etch back step may be performed until the titanium nitride film **004** outside the contact hole **020** is exposed. A contact structure following a tungsten etch back step is shown in FIG. 2A. In order to prevent residual tungsten from remaining outside the contact hole **020**, a tungsten etch back may include overetching. Consequently, as shown in FIG. 2A, the tungsten **005** remaining in the contact hole **020** may be recessed with respect to the top surface of the titanium nitride film **004** and/or titanium film **003**.

Following the etch back of a tungsten film **005**, the titanium film **003** and titanium nitride film **004** may be etched. Such an etch may be selective between tungsten **005** and the titanium film **003**/titanium nitride film **004**. Portions of the titanium/titanium nitride films (**003/004**) outside the contact hole **020** can be removed, leaving a contact structure with a tungsten plug **005** that has a projecting shape as shown in FIG. 2B.

To form tungsten **005** with a projecting shape, the deposited thickness of the titanium/titanium nitride films (**003/004**) can be equal to or greater than a recess generated when tungsten **005** is etched back.

One specific example of a titanium/titanium nitride film (**003/004**) etch may be

performed under the following conditions. Etch gases may include chlorine gas (Cl_2) flowing at about 10 sccm and Ar flowing at about 30 sccm. An etch chamber may be at a pressure of about 200 mTorr. Such an etch may be a reactive plasma etch with an RF power of about 300 W.

Following the formation of a tungsten plug with a projecting shape, an interconnect film may be formed over a semiconductor substrate **001**, including over the tungsten plug **005**. An interconnect film may include aluminum, as but one example. Such an interconnect film may then be patterned to form an interconnect structure **006**. A semiconductor device following the formation of an interconnect structure **006** is shown in FIG. 2C.

In this way, according to a first embodiment, a contact structure can be formed with a tungsten plug **005** that has a projecting shape, as opposed to a recess. Such an advantageous shape may be formed by depositing a titanium film **003** that is thicker with respect to other conventional approaches. In this way, plug loss may be prevented.

In addition, because a titanium film **003** of a first embodiment may be deposited with an anisotropic sputtering method, a titanium film **003** thickness within a contact hole **020** may be less than a thickness outside the contact hole **020**. In this way, a thicker titanium film **003** can be provided without narrowing a contact hole **020** opening, as is the case of other conventional approaches. Because a contact hole **020** opening is not reduced, a contact hole **020** may be more easily filled and may not suffer from higher resistance, as in other conventional cases as described above.

Having described one particular embodiment for forming a contact structure that extends between a interconnect structure **006** and a semiconductor substrate **001**, a second embodiment will now be described that may form a contact structure between two interconnect layers (i.e., a

via).

Referring now to FIG. 7A, a second embodiment may include forming a lower interconnect **009** on a first interlayer insulating film **007**. A second interlayer insulating film **008** may then be formed over the lower interconnect **009**. As but one example, a second interlayer insulating film **008** may comprise silicon dioxide (SiO_2), while a lower interconnect **009** may comprise aluminum.

As shown in FIG. 7A, a via hole **021** may be formed through a second interlayer insulating film **008** to a lower interconnect **009**. A via hole **021** may have an aspect ratio greater than 4, more particularly about 5 or more. A via hole **021** may also have an inner diameter less than 0.3 μm, more particularly about 0.2 μm, and a depth greater than 0.8 μm, more particularly about 1.0 μm.

As shown in FIG. 7B, a titanium film **003** may then be formed on the surface of the second interlayer insulating film **008**, including within the via hole **021**. A titanium film **003** may have a thickness outside a via hole **021** of about 100 nm or more, preferably 150 nm or more. In a similar fashion to the first embodiment, a titanium film **003** thickness may be selected by taking into account a via hole diameter. For example, a via hole may have a diameter of 300 nm or less, more preferably 250 nm or less.

Like the first embodiment, a titanium film **003** thickness should preferably be large enough to prevent a recess in a subsequently formed plug. A titanium film **003** should also have sufficient thickness within a via hole **021**. If a titanium film **003** is too thin, it may not serve as an adequate barrier between a semiconductor substrate **001** and other via materials and/or its adhering properties may be inadequate. Conversely, a titanium film **003** should not be too thick, as a via hole **021** opening may become too narrow, making it more difficult to

subsequently fill the via hole **021**.

According to the second embodiment, a titanium film **003** may be deposited with an anisotropic sputtering method. Such a method may generate sputtering particles that have a substantially vertical incidence with a semiconductor substrate.

Various anisotropic sputtering methods were previously listed. For the particular second embodiment described herein, a collimate sputtering method will be described in more detail.

A collimate sputtering apparatus is shown in FIG. 12. A collimate sputtering apparatus may include a substrate holder **031** that can hold a semiconductor substrate **032** in an essentially parallel orientation to a target **035**. A target **035** may be formed from a material that is to be deposited (e.g., titanium).

A target **035** may be connected to a DC power source **034** while a substrate holder **031** may be connected to ground. A magnet **033** may be disposed on one surface of the target **035**, while an opposite surface can face a semiconductor substrate **032**. The apparatus of FIG. 12 further includes a shielding plate, referred to herein as a collimator **038**. A collimator **038** may be disposed between the target **035** and the semiconductor substrate **032**.

A collimator **038** may discriminate between sputtering particles **037**. More particularly, of the various sputtering particles **037** released from the target **035**, a collimator may only allow particular sputtering particles **039** to pass through to a semiconductor substrate **001**. Particular sputtering particles **039** may be those sputtering particles having an essentially vertical incidence with a semiconductor substrate **001**. In this way, in a collimate sputtering method, particular sputtering particles **039** may be selectively passed through to a semiconductor substrate **001**, thereby providing an essentially anisotropic sputtering of a

material (e.g., titanium).

As but one specific example, a collimate sputtering method may have the following conditions. A sputtering chamber may have an aspect ratio of about 2. A sputtering chamber pressure may be about 2 mTorr. A substrate temperature may be about 200 °C. A DC power may be about 1.5 kW.

Referring back to FIG. 7C, following the essentially anisotropic sputtering of titanium, a titanium nitride film **004** may be formed. A temperature cycling step may then be performed to further improve the adhering characteristics of a titanium/titanium nitride film (**003/004**). A temperature cycling step may be a ramp anneal, as but one example.

Referring now to FIG. 7D, a tungsten film **005** may then be deposited. A tungsten deposition step may include a mixed gas that includes a tungsten source gas, such as tungsten hexafluoride (WF_6).

Following the deposition of a tungsten film **005**, a tungsten film **005** can be etched back to form a plug. Preferably, a tungsten etch back step may have a degree of selectivity between tungsten and titanium nitride. A tungsten etch back step may be a reactive ion etch with an etch gas that includes fluorine.

A tungsten etch back step may be performed until the titanium nitride film **004** outside the via hole **021** is exposed. A contact structure following a tungsten etch back step is shown in FIG. 8A.

Following the etch back of a tungsten film **005**, the titanium film **003** and titanium nitride film **004** may be etched. Such an etch may be selective between tungsten **005** and the titanium film **003**/titanium nitride film **004**. Portions of the titanium/titanium nitride films (**003/004**) outside the via hole **021** can be removed, leaving a contact structure with tungsten

plug **005** that has a projecting shape as shown in FIG. 8B.

To form a tungsten plug **005** with a projecting shape, the deposited thickness of the titanium/titanium nitride films (**003/004**) can be equal to or greater than a recess generated when tungsten **005** is etched back. A titanium/titanium nitride film (**003/004**) etch may be a reactive plasma etch with a source gas that includes chlorine.

Following the formation of a tungsten plug with a projecting shape, a second interconnect film may be formed over a semiconductor substrate **001**, including over the tungsten plug **005**. A second interconnect film may include aluminum, as but one example. Such a second interconnect film may then be patterned to form a second interconnect structure **010**. A semiconductor device following the formation of a second interconnect structure **010** is shown in FIG. 8C.

In this way, according to a second embodiment, a via structure can be formed with a tungsten plug **005** that has a projecting shape, as opposed to a recess. Such an advantageous shape may be formed by depositing a titanium film **003** that is thicker with respect to other films than conventional approaches. In this way, plug loss in a via may be prevented.

In addition, because a titanium film **003** of a second embodiment may be deposited with an essentially anisotropic sputtering method, a titanium film **003** thickness within a via hole **021** may be less than a thickness outside the via hole **021**. In this way, a thicker titanium film **003** can be provided without narrowing a via hole **021** opening, as is the case of other conventional approaches. Because a via hole **021** opening is not reduced, a via hole **021** may be more easily filled and may not suffer from higher resistance, as in other conventional cases as described above.

While the first and second embodiments have described particular approaches to

anisotropically sputtering a particular layer (e.g. titanium), as noted above, other methods may be used. For example, a third embodiment may follow the various steps of the first or second embodiments, but may include a different method for anisotropically sputtering a titanium film. Such a different method may include a long throw sputtering method.

A long throw sputtering apparatus is shown in FIG. 13. A long throw sputtering apparatus may include a substrate holder **031** that can hold a semiconductor substrate **032** in an essentially parallel orientation to a target **035**. A target **035** may be formed from a material that is to be deposited (e.g., titanium).

A target **035** may be connected to a DC power source **034** while a substrate holder **031** may be connected to ground. A magnet **033** may be disposed on one surface of the target **035**, while an opposite surface can face a semiconductor substrate **032**. The application of a voltage to a target **035** can generate sputtering particles.

A long throw sputtering apparatus may differ from a conventional sputtering apparatus in a chamber pressure and/or in distance between a target **035** and semiconductor substrate **032**. For example, in a conventional sputtering apparatus, such as that shown in FIG. 10, sputtering may be conducted at a pressure in the general range of 2.0 to 10.0 mTorr. In contrast, according to one embodiment, a long throw sputtering method may be performed at a lower pressure, such as 1.0 mTorr or less. In addition, or alternatively, the distance between a target **035** and a semiconductor substrate **001** may be about three to six times longer than in a conventional sputtering apparatus.

A lower sputtering chamber pressure can result in a longer mean free path for sputtering particles. Consequently, sputtering particles **039** released from a target **035** may have straighter paths, and not be scattered multiple times, as in a conventional sputtering

process.

A longer distance between a target **035** and a semiconductor substrate **032** may lead to more sputtering particle anisotropy. More particularly, those particles that are released at an angle that is tilted with respect to a semiconductor substrate **032** (i.e. have substantially non-vertical path components) may attach to side walls of a sputtering chamber. Thus, substantially most of the sputtering particles that may reach a semiconductor substrate **001** have an essentially vertical incidence, thereby providing an essentially anisotropic sputtering of a material (e.g., titanium).

While the various embodiments have been described with respect to contact holes and/or via holes having diameters of 0.3 μm or less, such particular contact sizes and shapes should not be construed as necessarily limiting the invention thereto.

However, the present invention may provide advantages at such smaller contact hole size. In particular, a method according to the present invention may be advantageous with contact/via holes that are smaller than 0.3 μm, more particularly contact/via holes with a diameter of 0.25 μm or less. For such smaller contact/via holes, tungsten may often be used as a plug material, and so may be subject to possible defects as previously described. While approaches may seek to improve deposition characteristics, such improvements may limit the degree of freedom in a process, such as the selection of a particular barrier metal film, or the like. Thus, for smaller contact/via hole sizes it can be difficult to realize reductions in plug loss while at the same time providing satisfactory film deposition characteristics. The present invention can provide for satisfactory deposition characteristics while at the same time reducing plug loss.

The various embodiments have described structures and methods for forming a

contact structure (including a via) that includes a first film (e.g., titanium) that is anisotropically deposited prior to a hole filling film (e.g., tungsten) that may form a plug. An anisotropic deposition may include an ion metal plasma method, or the like. In one arrangement, a first film thickness outside a contact hole may be 100 nm or greater. Consequently, following an etch back of the hole filling film and first film, a plug may have a shape that includes an upwardly projecting portion. In this way, a contact/via hole may be filled without necessarily incurring plug loss and/or increased resistance.

While the various particular embodiments set forth herein have been described in detail, the present invention could be subject to various changes, substitutions, and alterations without departing from the spirit and scope of the invention. Accordingly, the present invention is intended to be limited only as defined by the appended claims.